Techno-Economic Analysis of Hybrid Renewable Energy System for a Rural Community Health Centre in Uganda

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Abstract. The total power generation of Uganda stands at 1,777 MW which is far below phase two target for the National Development Plan II of 2,325 MW. To achieve the NDP II. To guarantee a sustainable development, the use of renewable energy mostly solar photovoltaic must be fast-tack. Solar technology in Uganda is moderately expensive as a result of high initial investment cost, this necessitates the need to diversify the energy mix of the country thus enhancing security of energy supply which formed the subject of this study. This study dealt with the techno-economic analysis of a hybrid Power system for Busitema Health Centre III. The daily energy demand for the health Centre was 3.979 kWh. The Net Present Cost, Levelized Cost of Electricity and Energy Output of the optimal system were determined using HOMER Pro software. Various combinations were obtained from the HOMER optimization simulations. From the analysis, a solar PV-diesel hybrid system stood out as the optimal configuration. This system is a 15.75 kW Solar PV, 10 kW diesel generator, and a battery bank capacity of 3,375AH.

Keywords: PV-diesel hybrid system; Techno-economic analysis; HOMER simulation; Rural Electrification; Uganda

1 Introduction

Energy is the engine for economic growth and development of any country [1]. For a sustainable development, access to energy services must not only be reliable, but also affordable and with low greenhouse gas (GHG) emissions [2]. Access to modern energy services in the developing world is still lacking, with over 620 million people not having access to electricity, while the proportion having access relies on a very expensive and low-quality supply [3]. Hybrid energy systems are a solution to the electrification challenge of

most rural areas in Africa. Depending on the resource potential of a geographical area, different energy technologies can be combined to have a technically and economically sounding power generation system. Optimization of the hybrid power generation systems guarantees the lowest investment cost while using renewable energy resources. To ensure that global warming remains below 2°C as recommended by Paris Agreement in 2015, it is thus critical to fast-track use of renewable energy (RE) and energy efficiency (EE) techniques to de-carbonize energy supply. There is therefore the need to focus on RE technologies.

Uganda's per capita electricity consumption is still low, and is about 215 kWh per capita per year [4]. However, it is richly endowed with substantial and diverse energy resources of both renewable and conventional; they are found fairly distributed across the country. Uganda has the hydropower potential of about 2000 MW and an average solar irradiation of 5.1 kWh/m^2/day on a flat surface suitable for photovoltaic applications in the country. The biomass potential for Uganda is estimated to be over 284 million tonnes of standing biomass stock. The potential for geothermal is estimated at 450MW, peat at 800MW and crude oil at 3 billion barrels [5]. The objectives of energy access have been included in the National Development Plans II and III [6]. According to the Rural Electrification Strategy Program Projects, by 2030 the pace of accelerating electricity access is projected to be at 51% and by 2040 to be at 100% [9, 10]. The Ugandan government has a target of achieving 26% electricity access in rural areas by 2022. This is intended to be done by increasing the use of sustainable and green energy sources from 4% to 61%. However, even with such efforts, millions of people in the country still do not get reliable and modern energy services. The variable nature of RE resources among other factors necessitates the combination of different RE resources together with or without a conventional source. The combination of different RE resources gives a hybrid system that is flexible, cost effective, reliable and efficient. The aim of the research was to develop an optimally sized cost-effective hybrid power system.

2 Methodology

2.1 HOMER Software

The HOMER Pro developed by the National Renewable Energy Laboratory in 1993 was used in this work. This computer model simplifies the task of evaluating the design possibilities of off-grid and on-grid power systems. This software performs three important tasks including simulation, optimization and sensitivity analysis. In the simulation process, it models the system and determines its technical feasibility and life cycle cost. In the optimization process, Homer does simulation on various system configurations to give optimum configuration. And finally in the sensitivity analysis process, the software performs numerous optimizations under a range of inputs in order to assess the impact of uncertainties in the inputs of the model [11].

HOMER uses different dispatch strategies to control the operation of the power generator(s) and the battery storage when the renewable energy to supply the load is not sufficient. HOMER models two main types of dispatch strategies namely: cycle-charging and load following. In load-following dispatch (LF), renewable power sources are used to charge the battery bank but generators only produce power to serve the load while in cycle-charging dispatch (CC), generators produce more power than required to serve the load and the excess electricity is used to charge the battery bank.

2.2 Location and description of Busitema Health Centre III

Busitema Health Centre III (case study) is located in Busia district, about 171 km East of Kampala, Uganda (see Figure 1). The location has coordinates of 0°28'01.0"N, 34°05'24.0"E,1,198 meters above sea level. It was established in 1967 as a health centre II to serve patients from several sub-counties including Busitema, Buteba, and Sikuda, among others. The health center is for a rural community and has got the capacity to handle 2,500 patients per month which falls under category I according to USAID. The load demand is between 5 and 10 kWh/day.

Fig. 1. Location of Busitema Health Centre III (Source: Google Maps).

3 Data collection and resource assessment

The meteorological data (solar insolation, wind speed, ambient temperature) were obtained from the National Meteorological Centre, Luzira, Kampala. The data were captured at the automatic whether station located in Tororo, which is the nearest weather station to Busia district.

3.1 Solar resource data Location and description of Busitema Health Centre III

Understanding the concept of irradiance on a collector's surface is important for the assessment of solar energy resource. Most weather stations record the total irradiation on a flat surface also known as Global Horizontal Irradiation which is the sum of the sun's radiation directly incident on the surface of the earth and the Diffuse Horizontal Irradiance [12]. The weather station in Tororo, captures data in time interval of 15 minutes. The monthly radiation of Busia is shown in Figure 2. The scaled annual average solar irradiation at the site was 5.15 kWh/m^2/day.

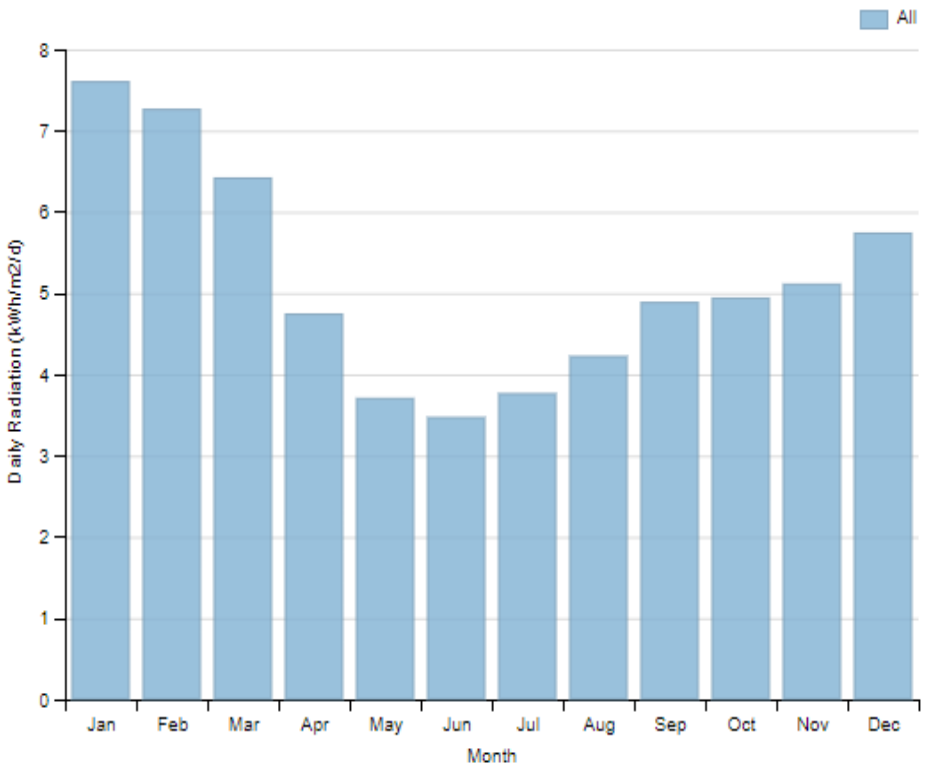


Fig. 2. Monthly radiation of Busia (Source: Modified NASA Database of HOMER Pro .13. 2).

3.2 Wind resource data

Wind speed at certain hub height is vital in quantifying wind potential of any given area. Wind data is always measured at a hub height of 10m mainly for weather prediction purposes. Busia district where the health centre is located has an annual average wind speed of 2.41 m/s at the height of 10 m. The average wind speed of Busia is shown in Figure 3.

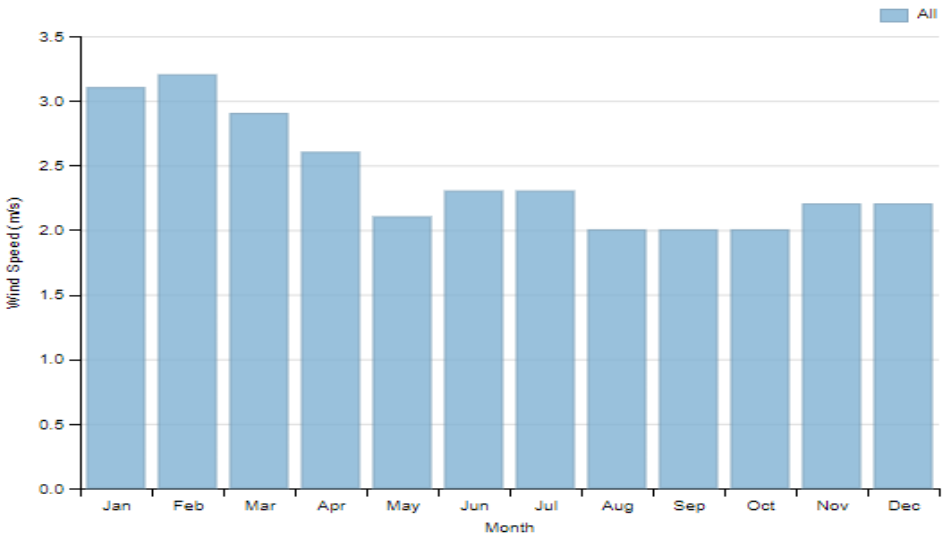


Fig. 3. Monthly average wind speed of Busia.

3.3 Ambient temperature

The monthly ambient temperature shown in Figure 4 at the case study site is an important parameter since solar PV cells' performance has a negative correlation with ambient temperature. The highest temperature was obtained in March during the dry season, while the least is obtained in June and July during the rainy periods.

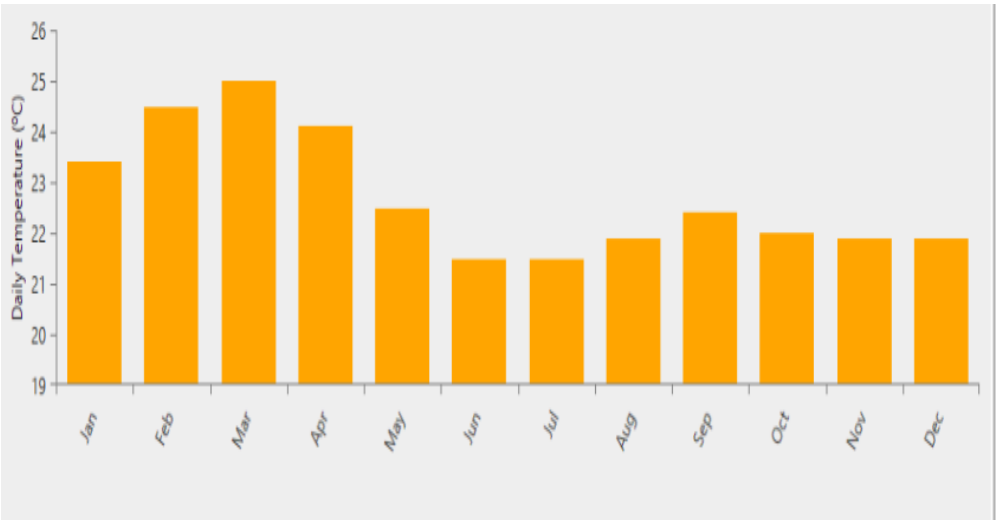


Fig. 4. Monthly average ambient air temperature of Busia.

3.4 Electric load data

The electrical load data for Busitema Health Centre III was obtained through site visit and having an interview with the technician of the health Centre. The typical daily load profile of the health Centre was generated from the data presented in table 1. The category of load profile was community since the health Centre is for a community.

Table 1: The daily demand for the health centre.

Load	Quantity	Rated power (W)	Watt Hour/Day	Duration (hr)	Total Load (watts)	Total Watts Hour (W)
Lighting Bulb	14	7	06:00pm 7:00am	13	98	1,274
Printer	1	696	8:00am - 3:00pm	7	696	4,872
Monitor	1	360	8:00am - 3:00pm	7	360	2,520
Television	1	50	8:00am - 3:00pm	7	50	350
CPU	1	360	8:00am - 3:00pm	4	360	1,440
Vaccine Fridge	1	130	00:00am-11:00pm	24	130	3,120
Microscope	1	60	8:00am - 1:00pm	5	60	300
Battery Backup	1	390	00:00am-11:00pm	24	390	9,360
Landline phone	1	10	00:00am-11:00pm	24	10	240
Cell Phone	6	5	8:00am - 3:00pm	7	25	175
Kettle	1	1800	8:00am - 11:00am	3	1800	5,400
Total (kW)					3.979	

3.5 Modelling of hybrid system components

The hybrid power system is made up of different electrical components which perform functions such as Energy production, Energy storage and Control of electrical energy. These components are Solar PV panels, wind turbine, battery storage, inverter, controller, and cables. The flowchart for the selection of optimal system configurations is given in figure 5 below. The solar panels and wind turbine (s) are used jointly to compensate for the unpredictable nature of Renewable Energy sources, whereas the generator acts as a backup. The effective utilization of renewable resources can significantly reduce replacement, operation and maintenance costs of a hybrid system [13]. HOMER uses Table 2 to come up with an optimal system arrangement of the various components considered in the hybrid system plus a 10kW Generator.

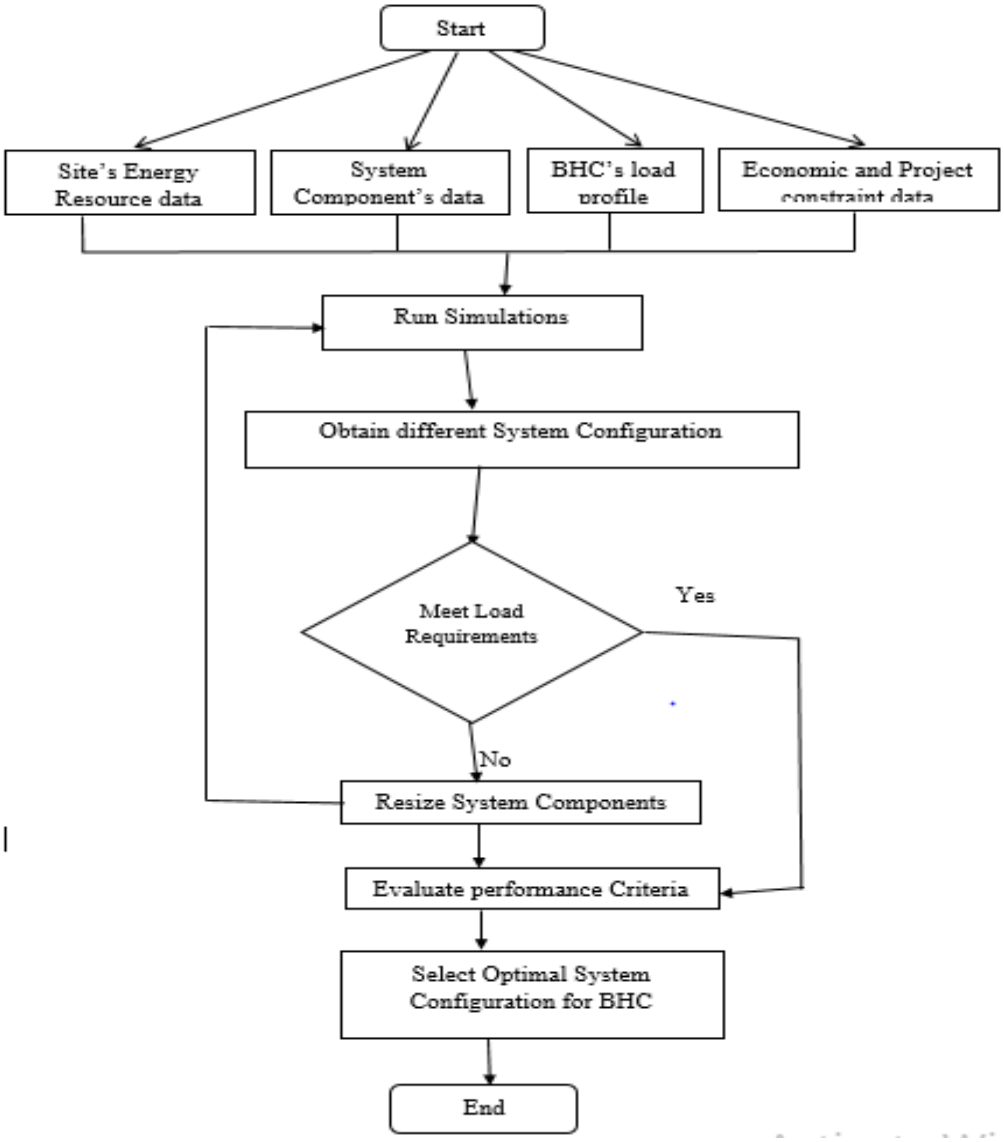


Fig. 5. Flowchart of the energy system configurations.

Table 2: Component sizes in HOMER.

Wind Turbine (Quantity)	PV array (kW)	Battery (string)	Converter (kW)
0	0	0	1
1	0.33	1	1.15
2	0.35	4	2
4	0.36	8	100
6	0.4	10	200

3.5.1 Modelling of solar PV array

A polycrystalline panel model Canadian Solar MaxPower CS6U-330P was used in the study because of its relative high efficiency (16.97%), robustness, outstanding low irradiance performance of 96.0% and relatively low price. Its specifications are shown in Table 3. Solar PV was the main electricity generator because of relatively high solar radiation in Eastern Uganda. The tracking system was not considered because the case study is located on a relatively clear and flat area. The Solar PV modules receive sunshine throughout the day at the angle of inclination of 44^{o}C. The angle of inclination depends of the latitude of the site.

Table 3: Design parameters for the solar PV modules.

Parameter	Unit	Value
Capital cost	Piece	150
Replacement cost	$/kW	150
Operation and maintenance cost per year	$/kW	50
Operating Temperature	^{o}C	-40 ~ +85
Derating factor	%	88
Efficiency	%	16.97

3.5.2 Wind turbine

The Aeolos 1kW vertical axis wind turbine was used in this study because it is a low start wind speed (since the site is a low windy area), quiet, safe, and reliable wind turbine. It also has high reliability in off-grid applications, and available in 48V off-grid or 110V on-grid applications. Table 4 shows the design parameters whereas Figure 6 shows the power curve for the selected wind turbine. To allow the software to find an optimal result; 0, 1, 2, 4, 6, 8 and 10 units were used in the software's search space.

Table 4: The design parameters of the wind turbine.

Parameter	Unit	Value
Capital cost	$	1,000
Replacement cost	$	1,000
O & M cost	$	0
Rotor Diameter:	m	2.0
Rated Power:	watts	1000
Cut-in Wind Speed	m/s	1.5
Rated Wind Speed:	m/s	10
Cut-out Wind Speed	m/s	50

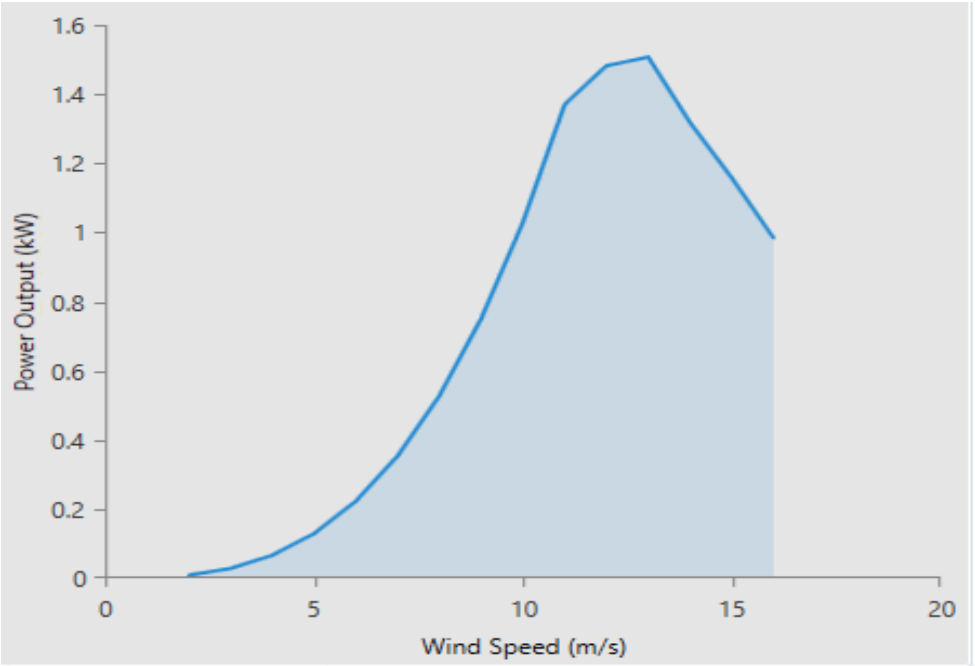


Fig. 6. Aeolos 1kW vertical axis wind turbine power curve (Source: HOMER PRO x643.13.2).

3.5.3 Battery Storage

When wind turbine and Solar PV generate more power than what the load can consume at the moment, the surplus energy is always stored in the batteries. The stored energy provides electricity during the future time when solar PV and wind are unavailable. The details of the Battery Model S-480 from Surrete Battery Company considered in modelling of the system are listed in Table 5. HOMER Pro optimizer determined the total number of batteries needed in this optimization study.

Table 5: Design parameters for the batteries.

Parameter	Unit	Value
Nominal Voltage	Volt	6
Nominal Capacity	KWh	2.89
Round trip efficiency	%	80
Maximum capacity	Ah	375
Capital cost	$	300
Replacement cost	$	300
Max charge current	A	135
Max discharge current	A	135
O & M Cost	$/Year	50

3.5.4 Converter

Both DC and AC power generators of the designed model are connected to an AC load. In order to have a constant flow of energy between AC and DC components, a converter is necessary. A CyboEnergy off grid CI-mini 1000N converter (specifications in Table 6) was used in the system and HOMER Pro software helped in optimizing the size. The size can then be reduced or increased according to the result of the simulation.

Table 6: Design parameters for the converter.

Parameter	Unit	Value
Capital cost	$	200
Replacement cost	$	200
O & M cost	$/year	0
Operational lifetime	Year	10
Efficiency	%	96

3.5.5 Diesel Generator

The generator chosen has a minimum load ratio of 25%. This is the percentage of the total load of the system below which the generator is turned off in order not to support the connected electric load. If the connected load is less than the minimum load ratio, the generator operates at a high load and the excess power produced can be used to charge the battery bank or dumped. When the load is powered by other energy sources in the system, the generator is turned off. A Generac 10kW diesel generator whose details are presented in Table 7 was chosen for modelling in this study because it is readily available on the Ugandan market.

Table 7: Design parameters for the diesel generator.

Parameter	Units	Value
Capital cost	$/kW	600
Replacement cost	$/kW	600
Operation and maintenance cost	$/h	0.3
Operational lifetime	Hours	15,000
Fuel curve intercept	L/h	0.48
Fuel curve slope	L/h/kW	0.286
Fuel Price	$/Litre	1.0
Power factor	%	80

4 Result and Discussion

HOMER Pro evaluated the operational characteristics of a hybrid system based on hourly time series simulation. These operational characteristics include annual electricity production, annual load served, excess electricity, renewable fraction among others. Optimization was caried out in order to come up with an appropriate optimal system.

4.1 The load profile of the health centre

The daily load data was put into HOMER software for simulation. The generic community profile data in Homer was edited with real load data to generate daily, monthly, seasonal, and yearly profile for the health centre as shown in Figure 7. The annual average power demand was calculated as 33.2 kWh per day with an estimated peak demand of 7.45 kW.

Fig. 7. A typical daily load profile (Source: HOMER Pro).

4.2 Results of modelling and simulation from HOMER Pro

A stand-alone off-grid system was modelled for the electrification of a Community Health Centre in Busitema. The designed system was an off-grid system having solar PV and wind turbine as the energy generation sources, batteries for storage, as well as a 10-kW diesel generator for backup (Figure 8). The sensitivity analysis was conducted on diesel price, inflation rate, annual average load, and average global solar irradiation, to understand their impact on the system's optimal solution. HOMER software was used to obtain the sizes for different components of an optimum configuration meeting load requirements at the lowest costs. The simulation was performed for each 8760 hours in a year and the key economic parameters in this study were the Net Present Cost (NPC), Levelized Cost of Energy (LCOE) and Operating Cost.

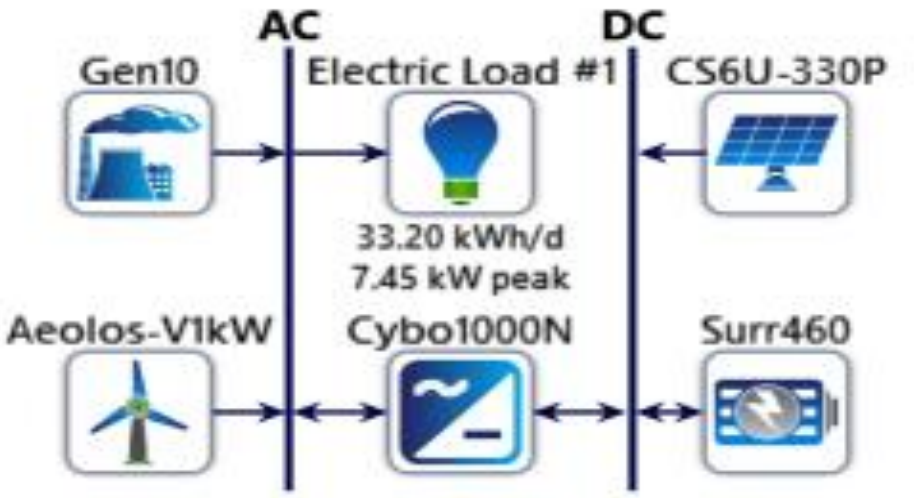


Fig. 8. Schematic diagram of the simulated hybrid system (Source: HOMER Pro).

4.3 System's control parameters, economic inputs, and constraints

4.3.1 Dispatch strategy

Both Load Following (LF) and Cycle Charging (CC) dispatch strategies were considered in this study, but the optimal solution had LF dispatch. The optimal dispatch strategy for a power system depends on different parameters like generator size, generator's operation and maintenance cost, fuel price, battery bank size and renewable energy resources.

4.3.2 Technical and economic inputs and constraints

In a Techno-economic analysis of any power system, constraints are prerequisites which must be fulfilled else HOMER disregards the systems not conforming to the set constraints. HOMER software inputs for the economic analysis include the nominal discount rate, expected inflation rate, the project lifetime in years, fixed capital costs of the system, operation and maintenance costs of the system, and the capacity shortage penalty. According to the Bank of Uganda, the nominal overall inflation rate for year 2019 was 3.94 %. The discount rate was modelled at 14 % for 25 years' project lifetime. In this work, the Renewable Fraction is taken as a range from 0 to 100 %; the maximum unserved energy is assumed to be 0% and the maximum annual capacity shortage is taken to be 0%. Hence, the designed system can serve all the annual load demand. The techno-economic model was developed using HOMER software, and a schematic overview of the designed simulated hybrid system is shown in Figure 8.

Since the load is based on AC, it is therefore connected to the AC bus. A CyboEnergy 1000N converter converts DC power to AC power. Solar PV produces DC power that charges the battery bank. HOMER will search for optimum system configuration and component sizes having the lowest Net Present Cost and give the simulation results based on technical,

economical and sensitivity analysis. 194,568 solutions were simulated from which 139,793 were found feasible. The 10 possible optimal solutions are presented in Table 8. The results of optimization show both the categorized and overall list of configurations available, based on the input data, and ordered according to the lowest NPC. This Table 8 presents the least cost-effective combinations from among all components' set-up based on their NPC. The optimal systems are selected after simulation depending on the Net Present Cost value. In order to analyse the technical feasibility of different power generating systems, electrical production, excess electricity generation, renewable fraction, cost of energy and capacity shortage are used. In this work, NPC and the LCOE were used as the economic criteria in determining the feasibility of the system.

The solar energy is only available during the day when there is sun shine. Wind Energy is not always available for all the time due to its intermittent nature. The configuration without battery storage would not be the best solution. Therefore, a battery is necessary to store energy for use when both sunshine and wind are not available. Is not advisable to discharge the battery to less than 70%, therefore it is necessary to have a backup diesel generator to account for fluctuations in the renewable energy resources. The system consisting of solar PV, genset and battery (S1) with LCOE of $0.265 was found out to be the most appropriate optimal system with 15.78 kW of solar PV and 9 strings of Surrette S-480 battery connected in parallel having 11.3 hours of autonomy. The configuration next to the best optimal solution is PV/Wind/Genset/Battery (S2) with LCOE of $0.283 and the same number of batteries as system S1, but a slightly smaller size of converter and solar PV of 6.17 kW. The base case is a system of a 10-kW diesel generator having NPC of $72,698 and LCOE of $0.703 with cycle charging dispatch strategy. The Wind/Genset/Battery (S10) was found out to be the most expensive configuration for electricity generation due to the high NPC of $75,578.

Table 8: System components' sizes, the NPC and the LCOE.

System Configuration	Type of System	Size of Solar PV(Kw)	Number of Wind Turbines	Size of Diesel Generator (kW)	Size of Batteries (Units)	Size of Converter (kW)	Net Present Cost ($)	Levelized Cost Of Energy ($)
PV/Genset/ Battery	S1	15.78		10	9	6.2	27,427	0.265
PV/Wind/Genset/Battery	S2	15.29	1	10	9	6.17	29,243	0.283
PV/Battery	S3	33.17			26	7.37	42,644	0.412
PV/Wind /battery	S4	35.13	1		24	7.36	44,499	0.43
Genset	S5			10			72,698	0.703
PV / Genset	S6	0.05		10		0.06	72,705	0.703
Genset / Battery	S7			10	1	0.25	73,525	0.711
Wind / Genset	S8		1	10			74,768	0.723
PV / Wind / Genset	S9	0.58	1	10		0.38	74,811	0.723
Wind/Genset/ Battery	S10		1	10	1	0.19	75,578	0.731

4.4 Electrical production

The results in Figure 9 and table 9 indicate that the system S4 with solar PV and wind turbines generates more power at 54,715 kWh/yr than the rest of the configurations. The optimal hybrid solar system S1 generates 26,231 kWh/yr which is enough to meet the AC consumption of the health Centre at 11,559 kWh/yr. The amount of power generated by the solar PV and wind influences renewable fraction (RF). The renewable fraction for System configurations S3 and S4 is high at 100 %, since they have solar PV and wind as the only power producing components in the configuration. Systems S1 and S2 follow closely with a small fraction of the energy coming from the diesel generator at 14.5% and 14.7% throughout the year.
System configurations S1 and S2 have a slightly lower renewable penetration than S2 and S3 as a result of the diesel generators generating electricity when the power stored in the batteries is inadequate. The energy from the diesel genset in S2 and S3 is 6.69 % and 6.91 % of the total production respectively; this indicates that a genset is just a backup when the battery is down. The base case S5 and S7 have only the genset as the source of power, and therefore their Renewable Fraction is zero. The RF of S6, S8, S9, and S10 is zero even though they have a renewable resource because almost all of that electricity generated is dissipated as excess power. The configuration having wind is not the best choice since wind speed in the case study is low.

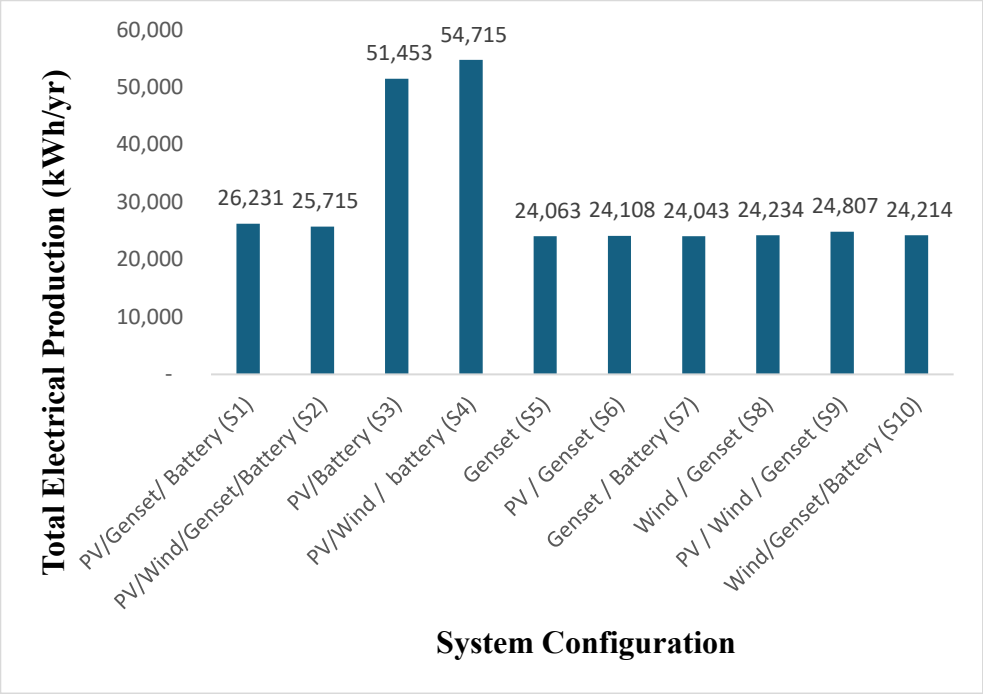


Figure 9: Total electrical production per system.

Table 9 : Electrical energy production per type of source.

System Configuration	Solar		Wind		Genset		Renewable Fraction (%)
	kWh/yr.	%	kWh/yr.	%	kWh/yr.	%	
PV/Genset/ Battery (S1)	24,476.0	93.300			1,755	6.69	85.5
PV/Wind/Genset/Battery (S2)	23,717.0	92.200	220	85.6	1,778	6.91	85.3
PV/Battery (S3)	51,453.0	100.000					100.0
PV/Wind/Battery (S4)	54,495.0	99.600	220	40.2			100.0
Genset (S5)					24,063	100.00	0.0
PV/Genset (S6)	76.6	0.318			24,031	99.70	0.0
Genset/Battery (S7)					24,043	100.00	0.0
Wind/Genset (S8)			220	90.9	24,014	99.10	0.0
PV/Wind/Genset (S9)	904.0	3.640	220	88.8	23,682	95.50	0.0
Wind/Genset/Battery (S10)			220	90.9	23,994	99.10	0.0

4.5 Excess Electricity

Most of the systems have large quantities of excess power as shown in Table 10. Nevertheless, the system was designed to meet all the annual load demand without any shortage since the capacity shortage during the simulation was set at 0 %. In Table 10, it is shown that S4 has the highest quantity of excess electricity at 75.6 % of the total production per year. This is because of the large size of the PV array and zero capacity shortage of the system. S2 has the least excess electricity at 48.0 % because of lower capacity of solar PV.

Table 10: Excess electricity from different system configurations.

System Configuration	Excess electricity (kWh/yr)	Percentage of Excess Electricity (%)
PV/Genset/Battery (S1)	12,939	49.3
PV/Wind/Genset/Battery (S2)	12,446	48.0
PV/Battery (S3)	38,060	74.0
PV/Wind/Battery (S4)	41,359	75.6
Genset (S5)	11,945	49.6
PV/Genset (S6)	11,989	49.7
Genset/Battery (S7)	11,926	49.0
Wind/Genset (S8)	12,116	50.0
PV/Wind/Genset (S9)	12,675	51.1
Wind/Genset/Battery (S10)	12,097	50.0

4.6 Cost analysis of the systems

Renewable energy systems are characterised by high capital costs due to the initial costs of equipment that need to be installed before the production of electricity. The cost of a power system is greatly influenced by the high cost of the balance of system equipment necessary to stabilize the renewable energy system. Solar and wind systems often need power generating equipment to be installed over a large piece of land to harness the energy. It is therefore very crucial to establish an optimal system for a particular location. The costs of the system configurations are broken down into different classes from initial capital costs up to salvage value. The capital cost for system S4 is $14,940.53 which is much higher when compared to that of system S1 which is at $ 6905.67 as shown in figure 10. Therefore, system configurations consisting of wind turbine for electricity production have higher initial capital cost than those without it. Although, the price of solar modules has reduced, most of the BOS (converter and battery) are still expensive and not as affordable as the modules. The price is also influenced by the size and capacity of the system. System S2 has the same number of batteries like S1 but with an additional more expensive wind turbine.

As shown in Figure 10, the Operation and Maintenance cost of the system with diesel genset and wind turbine is high; this is due to continuous expenses incurred in lubrication and spare parts associated with the genset and wind turbine, among others. In addition, the long operating hours of the diesel generator leads to wear and tear, and therefore require lubrication and repair in the event of breakdowns. When a diesel genset runs for many hours, the operation and maintenance costs will become high. Systems S3 and S4, have the highest salvage value at the end of the project life because of minimum running time of the genset. System S5 and S6 have the least salvage value because of tear and wear from the continuous operation of the generator, thereby reducing the value of the equipment at the end of the project.

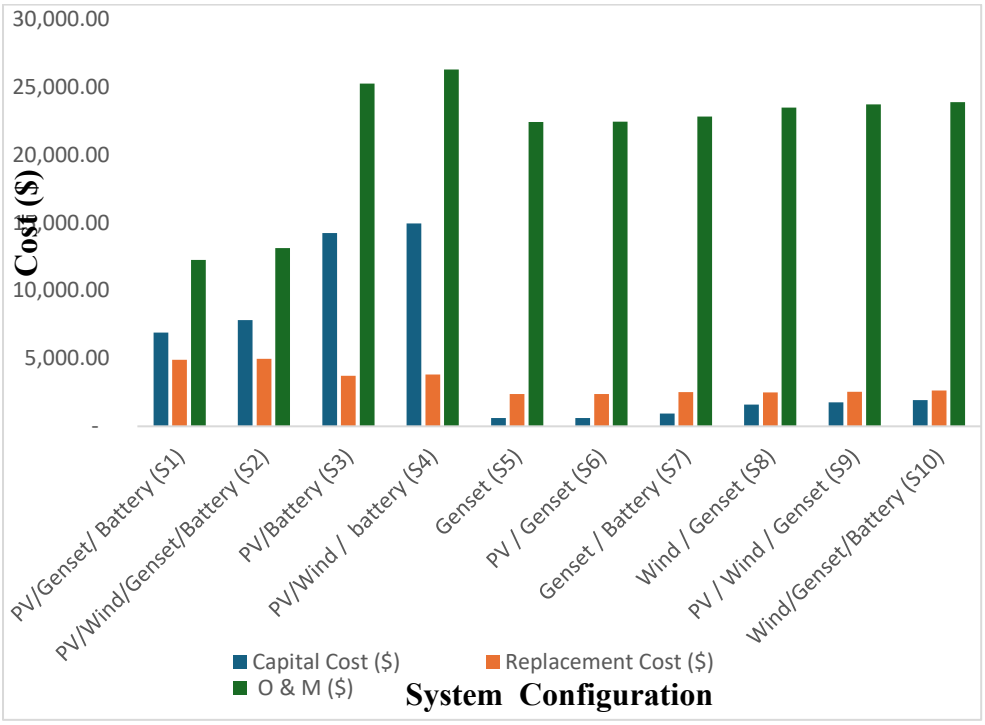


Fig. 10. Capital costs of different configurations of the system.

4.7 Fuel consumption

The number of hours a diesel genset runs plus the load it supplies determines the amount of diesel fuel it consumes. The selected 10 kW genset consumes enough diesel to power the all the loads of the health centre, particularly when it is used as the only power generation component. S5 consumes the highest amount of fuel at 11,08 litres per year, since the genset is the sole supplier of power. Systems S1 and S2 have low fuel consumption since they do not rely on a genset as a main producer of electricity needed. S3 and S4 have zero fuel consumption because the load is powered only by renewable sources including solar and wind, as shown in Figure 11. Operating diesel generator for long hours will lead to high consumption of fuel.

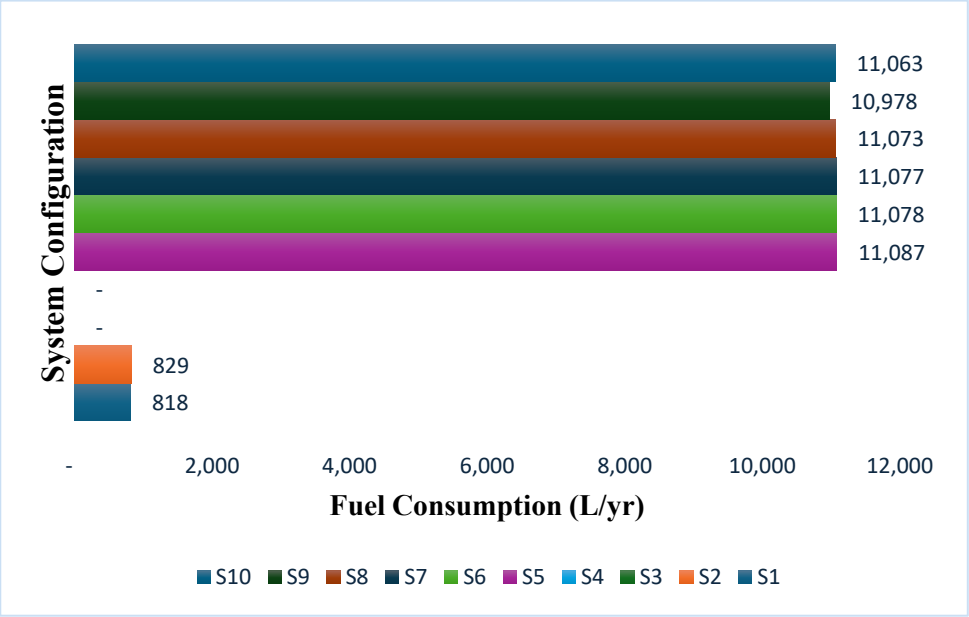


Fig. 11. Fuel consumption per system type

4.8 Carbon emissions

The annual carbon emissions depend on the amount of diesel the Genset consumes per year (Figure 12). A lot of CO_2 emissions are released from S5 to S10, this is due to the long hours of running the diesel generator. S5 releases high levels of CO_2 emissions per year because it consumes more diesel. System configurations S3 and S4 do not emit Carbon dioxide since they have no genset component. S1 and S2 release a negligible amount of CO_2 emissions when compared to the other configurations. Carbon-dioxide emission of the system is reduced by 92.63% from configuration S5 to (S1). The world is moving to a green economy; hence, a system having zero or negligible carbon emissions is desirable for a sustainable development.

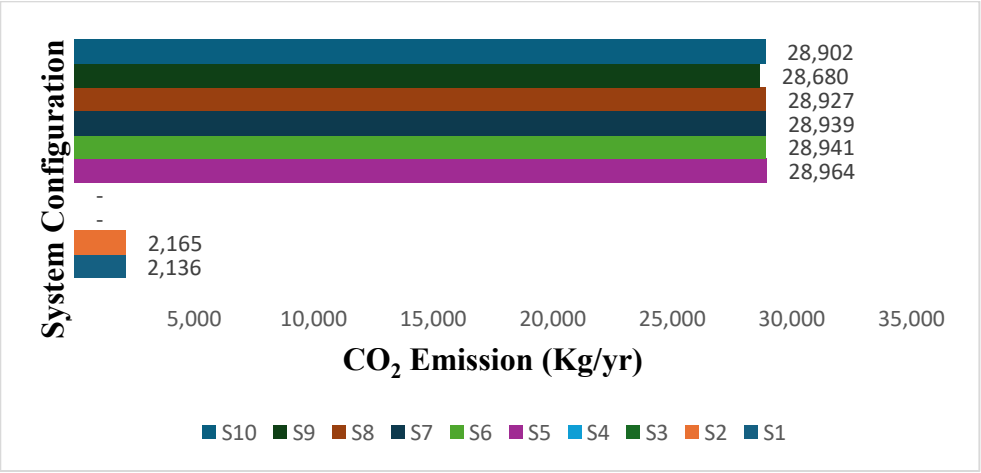


Fig. 12. CO_2 emissions per system configuration.

4.9 Sensitivity analysis of the system

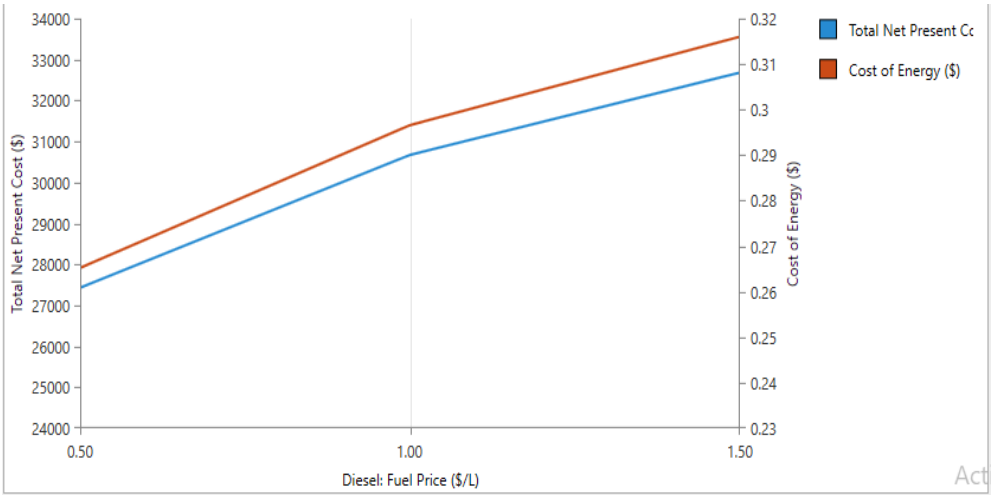
The sensitivity results show the effects of particular variables such as diesel price, discount rate, inflation rate, average wind speed, annual average load, average solar irradiation among others on the hybrid system. A sensitivity analysis is vital in analysing the impact of unknown variables on the performance of a power system, thus giving the effects of varying different resources and economic parameters. Some of the variables are either unknown or are those that constantly affect the economic performance of a country like expected inflation rate and discount rate. In this study, sensitivity analysis was done on diesel fuel price, inflation rate, average solar irradiation, and annual average load to understand their impact on the economic performance of the appropriate optimal system configuration as shown in Table 11.

Table 11: Sensitivity variable values.

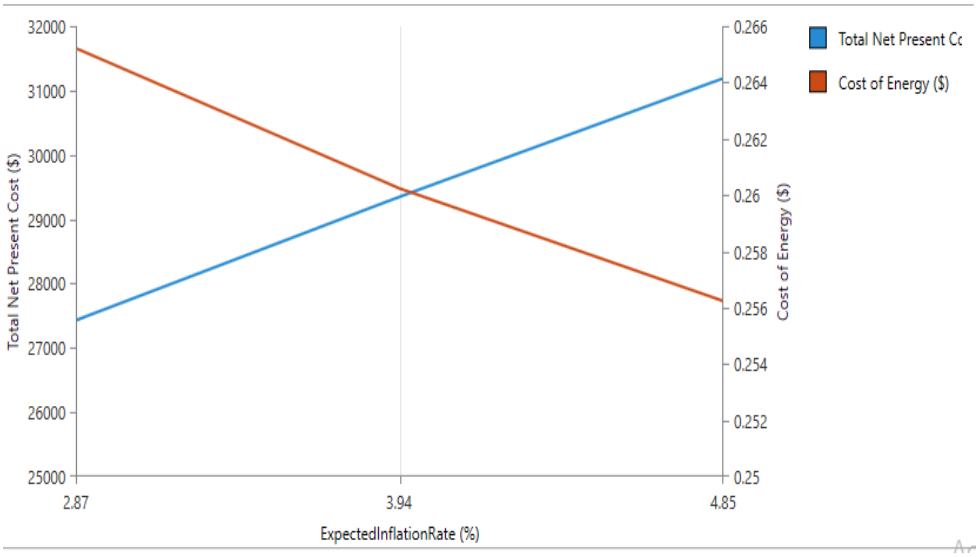
Diesel fuel price ($/Litre)	Inflation rate (%)	Solar radiation (kWh/m^2/day)	Annual average load (kWh/day)
0.5	2.87	5.15	33.20
1.0	3.94	5.90	36.52

4.10 The impact of diesel fuel price and inflation rate on optimal solution

The Net Present Cost is directly proportional to the diesel price as shown in Figure 13a. It was also found in Figure 13b that the NPC increase with increase in inflation rate, while the LCOE decreases with increase in inflation rate. At $0.5/L which is a base price value, the Net Present Cost is $27,426.650, as the price rises from $0.5/L to $1.0/L, the NPC increases to $30,669.560 as shown in Figure 14, therefore, as the diesel price increases by 100 %, the Net Present Cost increases by 2 %. A rise in the price of diesel from $0.5/L to $1.0/L causes the energy cost to increase from $0.265 to $0.297 as shown in Figure 15, which is 12 %. As the diesel price rises, the CO2 emissions are reduced significantly, this is because it will lead to a shift from diesel generators to renewable energy generation systems. An increase in inflation rate from 3.94 % to 4.85 % leads to a decrease of energy cost by about 2 %. This results in a total NPC of $31,187.04, which is a rise of 6.3 % compared to the base case.



a)



b)

Fig.13. Response of NPC and LCOE as (a) diesel price varies, and (b) inflation rate varies.

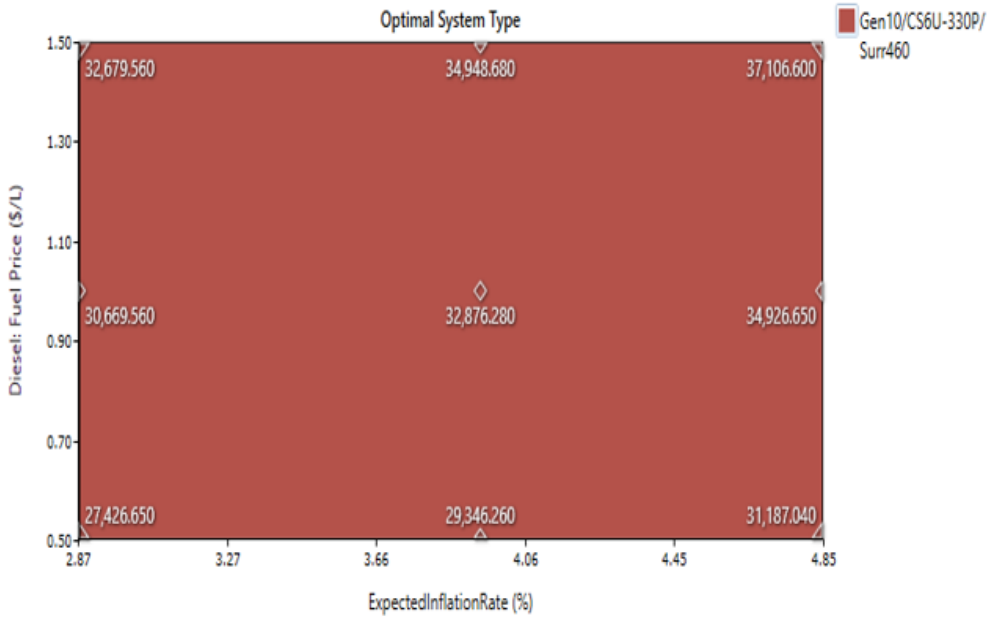


Fig. 14. Impact of varying fuel price and inflation rate on NPC.

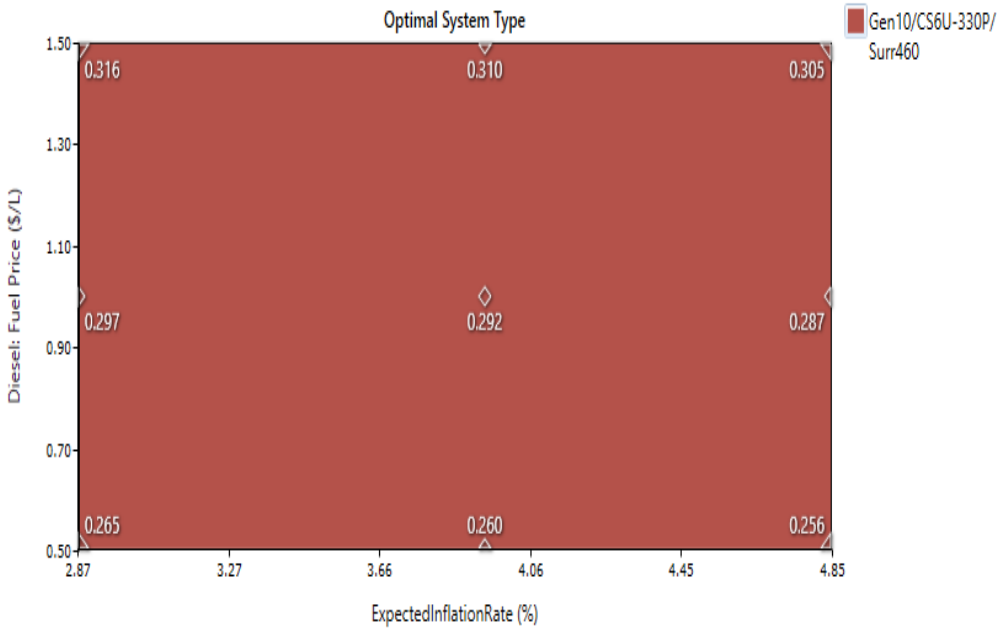


Fig. 15. The Effect of fluctuating fuel price and inflation rate on LCOE.

4.11 The impact of solar irradiation and annual load on optimal solution

In this work, the variation of average solar irradiation was from 5.15 kWh/m^2/day (as recorded at Tororo weather station) to 5.9 kWh/m^2/day (obtained from NASA database in HOMER Pro). Its effect on the optimal solution was analysed with NPC and COE. Both NPC and COE decrease with increase in average solar irradiation as indicated in Figure 16. By varying the average solar irradiation from 5.15 – 5.9 kWh/m^2/day, the COE of the optimal system S1 is reduced from \$0.265 to \$0.254 and the total NPC also decreased from \$27,426.650 to \$26,278.960 as shown in Figures 17 and 18 respectively. Higher solar radiation at the site lowers the value for Net Present Cost. This is because with a high solar irradiance at the site, the solar PV system will supply power to the load for a longer period of time. With this, the use of diesel genset and its associated cost will be reduced; this will bring about low NPC and will also lead to higher value of Renewable Fraction. The NPC increases from \$27,426.650 to \$29,742.910 as the electrical load demand increases as indicated in figure 18. This is because of the need to expand the system. It was further found out that the LCOE decrease from \$0.265 to \$0.261 at an average solar irradiation of 5.15kWh/m^2/day as shown in Figure 17.

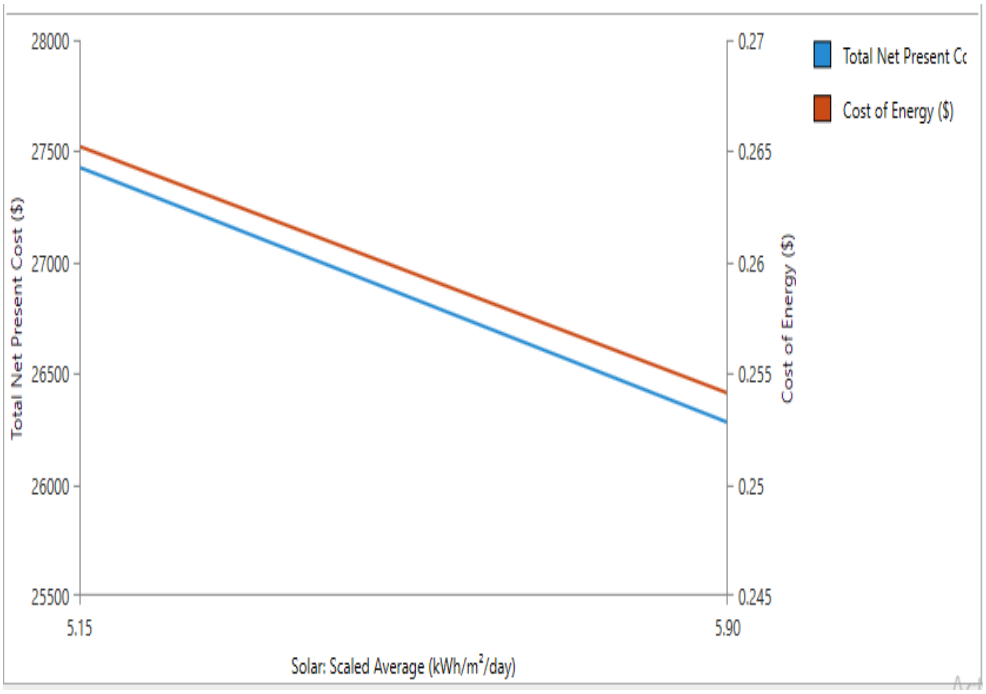


Fig. 16. NPC and LCOE as a function of average solar irradiation.

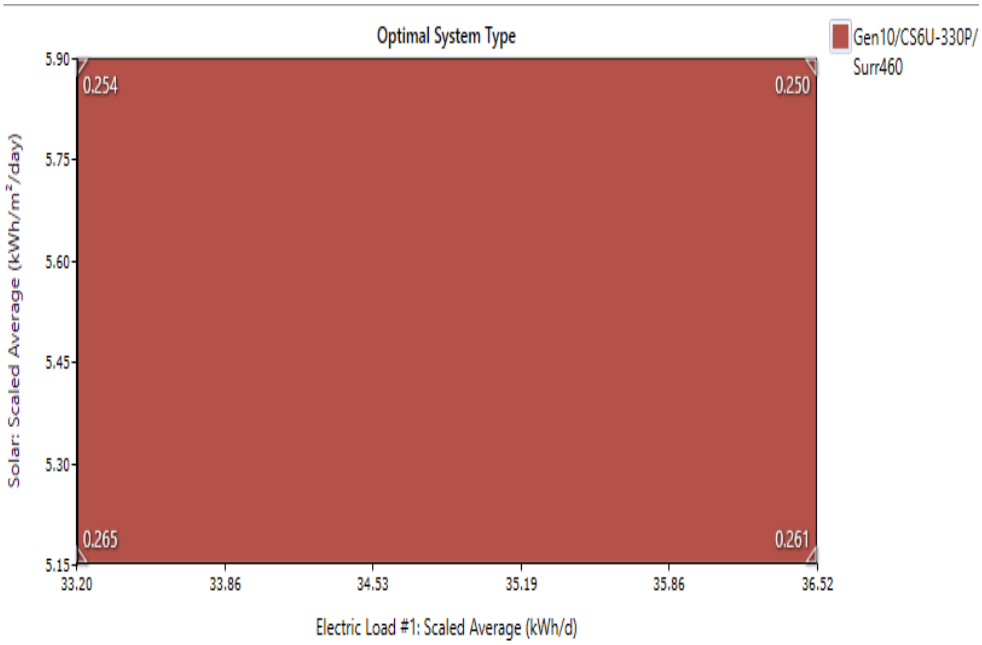


Fig. 17. Sensitivity of solar irradiation and average load superimposed with LCOE.

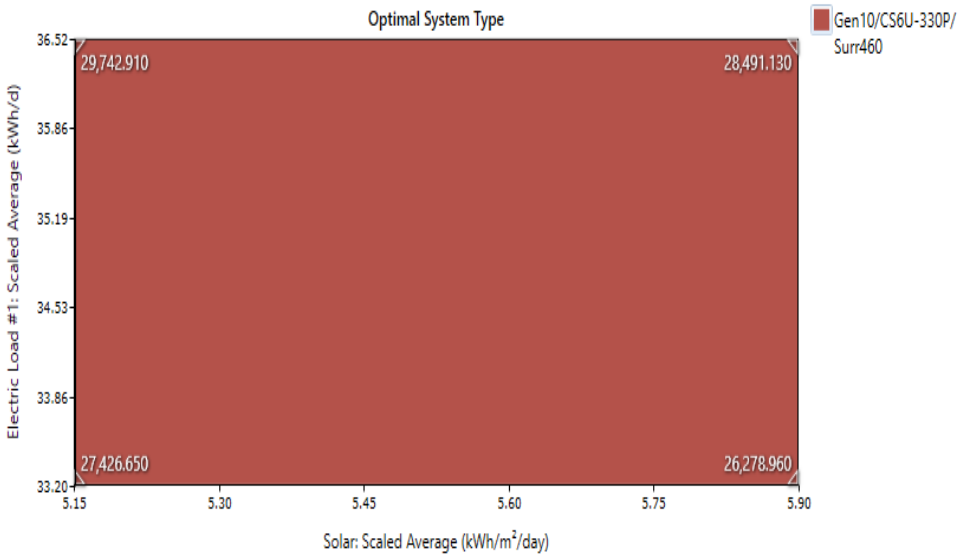


Fig. 18. Sensitivity of solar irradiation and scale average load superimposed with NPC.

5 Conclusion

In this work, the techno–economic analysis of the hybrid system was successfully done with the help HOMER Pro Tool. The findings have shown that wind energy potential of the location is considerably low. The analysis has shown that wind can be integrated with other energy sources systems such as PV, diesel generator to obtain a viable solution. The results showed that the available solar energy potential is utilizable in the study area. It was found

out that configuration S1 having solar PV, diesel Genset and a battery bank was the appropriate optimal system. The NPC of the optimal configuration was 22,427 USD and LCOE was 0.265 USD/kWh. The LCOE is about 39% higher than the 2019 electricity tariff developed by UMEME– power supply company in Uganda. Since the LCOE is high, the government will have to subsidize the system for the health Centre to afford it. The total electrical production, diesel fuel consumption and Carbon dioxide emission reduction for the optimal solution was also excellent.

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